HED Science Advisory Council for Exposure (ExpoSAC)
Policy/Guidance

Issue:	Assessment of Occupational Exposure for Post-Harvest Commodity Pesticide Treatments
Versions/Dates:	March 2012: initial version November 2016: handler unit exposures updated using AHETF data February 2018: sorter dermal exposure value correction in calculator
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Background/Introduction

Pesticides are commonly applied as a post-harvest treatment[1] to the following commodities:

- Pome fruit (e.g., apple, pear)
- Stone fruit (e.g., peach)
- Fruiting vegetables (e.g., tomato, pepper)
- Citrus (e.g., orange, tangerine)
- Tropical fruit (e.g., avocado, pineapple)
- Root vegetables (e.g., potato, turnip)
- Cucurbit vegetables (e.g., cantaloupe, cucumber)

This treatment is primarily made via automatic dipping or spraying as the fruits or vegetables pass down a conveyor belt, but can also be accomplished by spraying loaded trucks. This policy addresses the following exposure scenarios related to these types of treatment:

- Dermal and inhalation exposure during mixing/loading pesticide formulations for:
  - Large bins/vats to accommodate automatic dipping/spraying
  - Tank/containers used for hand sprays
- Dermal and inhalation exposure during application of sprays to loaded trucks
- Dermal and inhalation exposure during sorting/culling/packing treated fruits or vegetables
- Indirect inhalation exposure during automated application of dips or sprays

Post-harvest treatment equipment and procedures are considered substantially similar across all commodity types. Thus, unless additional chemical-specific information is available that can be used for refinement, the methodology outlined below is universally applicable.

Exposure Assessment Methodology

[1] http://www.fao.org/Wairdocs/X5403E/x5403e00.htm#Contents

This policy is designed to be applied in situations where there is a lack of chemical-specific information. The recommended methodology for post-harvest commodity treatments is largely based on one available worker exposure monitoring study:

> Maxey, S.W., and Murphy, P.G. 1994. Evaluation of Post-Application Exposures to Sodium O-phenylphenate Tetrahydrate/O-phenylphenol to Workers during Post-Harvest Activities at Pear and Citrus Fruit Packaging Facilities. Unpublished study by Dow Chemical. October 19, 1994. EPA MRID 43432901.

The study was reviewed by Versar, Inc. with a secondary review by HED[2]. The study adequately followed test guidelines as well as ethical requirements[3]; it is considered useful and applicable for a generic methodology for post-harvest pesticide treatment exposure assessment. An excerpt from the executive summary of Versar, Inc.'s primary review is below.

> The study was designed to quantify worker exposure to o-phenylphenol sodium salt (SOPP) and o-phenylphenol (OPP) during post-harvest pear and citrus fruit handling activities. A total of 62 females were monitored at six fruit packaging facilities (3 pear and 3 citrus) that were using commercially available SOPP-based liquid formulations, containing 12% to 22% OPP. Though the test substances monitored contained SOPP as the active ingredient, all measurements in the Study Report were reported in terms of OPP. The pears were treated with SOPP through a dip application and the citrus were treated with SOPP through either a foam or spray application. The treatment solutions contained between 0.14 and 1.29% OPP. The processing method between the facilities varied, however, at all facilities, the fruit was rinsed with water after treatment and prior to any handling by the workers monitored in this study.
>
> At each facility, a complete set of monitoring samples was collected from 5 sorters and 5 packers. The sorters inspected and graded treated fruit and the packers packaged treated fruit by hand or using a packaging machine (which also involved hand contact). All pear packers wore 2 to 3 cots on one hand to handle the pear packing paper and the majority of the pear packers also wore thin cotton gloves to protect their hands and fruit from physical damage. The citrus packers at one facility also wore gloves at times. The pear and citrus sorters did not wear gloves or cots, and a few workers wore tape at the end of fingers to protect the fruit.
>
> Dermal exposure was monitored through the use inner dosimeters (t-shirt), outer dosimeters (long-sleeve shirt), and hand washes. Exposures were not monitored for body portions below the waist. Inhalation exposure was monitored through the use of personal air sampling equipment. The inhalation collection media consisted of a PVC filter and silica gel sorbent tube, which were placed at the breathing zone of each worker and attached to an air sampling pump calibrated to deliver an air flow rate of approximately 1.0 liter per minute (LPM). Additionally, area air monitoring samples were collected from various locations inside the citrus packaging facilities.

Note that this study is proprietary (sponsored by Dow Chemical) and subject to Agency data protection provisions. Pesticides registered based on use of this methodology may be required to provide compensation.

Mixing/Loading/Application Exposure

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[2] Crowley, M. (2005) Review of "Evaluation of Post-Application Exposures to Sodium o-Phenylphenate Tetrahydrate/o-Phenylphenol to Workers During Post-Harvest Activities at Pear and Citrus Fruit Packaging Facilities". Internal Memorandum from Matthew Crowley to Rosanna Louie. D209211.

[3] Sherman, K. (2012). Ethics Review of Worker Exposure Study. Internal Memorandum.

Workers will mix and load pesticide formulations for both automated post-harvest commodity treatments and sprays for loaded trucks. However, for sprays to loaded trucks, the same worker is likely to mix/load and apply treatments with powered handguns.

Mixing/Loading Exposure for Automated Spray Treatments

In the case of automated treatments, workers will mix/load the pesticide formulation into large bins or vats to produce a dilute solution. For this scenario, the standard HED assessment methodology for handling pesticides is appropriate:

$$\text{Dose (mg)} = [\text{UE (mg/lb ai)} * \text{AaiH (lb ai)} * \text{AF}] \div \text{BW (kg)}$$

Where:

UE = unit exposure (expressed as amount of exposure per amount of active ingredient handled)

> Default estimates for formulation-specific mixing/loading dermal and inhalation unit exposures are provided in HED's "Occupational Pesticide Handler Unit Exposure Surrogate Reference Table" found on EPA's webpage detailing occupational handler exposure assessment[4]. Values are formulation-specific, including closed-system mixing/loading which is a potential scenario due to the large volumes being handled for dipping vats/bins.

AaiH = amount of active ingredient handled

> The amount of active ingredient handled is calculated using the application rate and, depending on the units given for the application rate, assumptions for amount of commodity to be treated or amount of solution volume to mix.
>
> The application rate is typically specified on the pesticide product label. In the case of commodity treatments, particularly those used in automated processes where the fruits and vegetables are treated on conveyer belts from large vats of diluted pesticide, this rate may appear on the label as "ppm" or as a "% solution". Rates may also appear as mass of product per mass of commodity (e.g., gallons product/ton). Regardless, rates should be converted in the equation to account for units in terms of amount of active ingredient handled.
>
> - If the application rate is given based on the amount of commodity (e.g., per ton of fruit) to be treated, the default estimate is **144,000 lbs**, calculated as the product of 90 lbs commodity per box, 200 boxes per hour, and 8 hours per day.[5] This is considered to be a conservative, high-end capacity estimate.

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[4] https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/occupational-pesticide-handler-exposure-data

[5] For additional reference, see: http://tru-juice.com/tw/about-process.htm and http://edis.ifas.ufl.edu/ae184

- If the estimate is given as a % solution and does not provide information on the amount of commodity to be treated, use a default estimate of **25,000 gallons**. This is based on MRID 43432901 referenced above which used 20,000 – 35,000 gallon vats for treatment of approximately 15,000 lbs of pears (300 boxes/day, 50 lbs/box). Use of this estimate assumes a worker is producing a fresh batch of pesticide treatment. In most cases, one batch can be used for several treatments, so it is unlikely that this amount of volume is handled on a regular basis.

BW = body weight

For adults (males and females combined) a default body weight of **80 kg** is recommended. A default body weight of **69 kg** is recommended for females (age 13 < 49), should it be required based on a chemical's toxicity.

AF = absorption factor (route-specific)

If no information is available, 100% absorption of external exposure is typically assumed when an oral toxicity study is used to estimate dermal and inhalation risk. Route-specific toxicity dosing studies, on the other hand, account for absorption.

Mixing/Loading/Application Exposure for Direct Sprays

Direct dermal and inhalation application exposure is likely only for post-harvest treatments where workers spray loaded trucks. For mixing/loading/applying direct sprays, the standard HED handler (similar to mixing/loading exposure described above) assessment applies:

$$\text{Dose (mg)} = [\text{UE (mg/lb ai)} * \text{AR (lb ai/gallon)} * \text{AVH (gallons)} * \text{AF}] \div \text{BW (kg)}$$

Where:

UE = unit exposure (expressed as amount of exposure per amount of active ingredient handled)

Default estimates for dermal and inhalation unit exposures are provided in HED's "Occupational Pesticide Handler Unit Exposure Surrogate Reference Table" as previously described. Since no monitoring data are available for this type of application, assessors should use the estimates for "mechanically-pressurized handgun sprayer; orchards, vineyards, etc." as a reasonable surrogate. Note that these data reflect exposure during the mixing/loading process in aggregate with application exposure, as these tasks are typically performed by the same individual for this type of application.

AR = application rate

The application rate is typically specified on the pesticide product label. To ensure proper units, it should be expressed in terms of "mass active ingredient per volume solution". This may require conversion for labels that express diluted solutions as "ppm" or "% solution".

AVH = amount of volume handled

> If the application rate is given based on the amount of commodity (e.g., per ton of fruit) to be treated, the default estimate is **144,000 lbs**, calculated as the product of 90 lbs commodity per box, 200 boxes per hour, and 8 hours per day (see previous description).
>
> For application rates expressed in terms of a dilute spray volume (e.g., amount of chemical per volume of solution) a default estimate of **1000 gallons** is recommended for mechanically pressurized handgun sprayers.

AF = absorption factor (route-specific)

> If no information is available, 100% absorption of external exposure is typically assumed when an oral toxicity study is used to estimate dermal and inhalation risk. Route-specific toxicity dosing studies, on the other hand, account for absorption.

BW = body weight

> For adults (males and females combined) a default body weight of **80 kg** is recommended. A default body weight of **69 kg** is recommended for females (age 13 < 49), should it be required based on a chemical's toxicity.

"Post-application" Exposure during Automated Post-Harvest Treatments

During automated treatments, dermal and inhalation exposure is anticipated for workers performing sorting, culling, and packing tasks. Since the workers experience exposure following the treatment, this is technically "post-application" exposure; however, unlike other post-application activities (e.g., harvesting, scouting, etc.), this treatment is not governed by the Worker Protection Standard (WPS) and potential re-entry intervals (REIs). Additionally, for workers in the warehouse or packaging facility not directly involved in the automated treatment process, there is potential for indirect inhalation exposure. Exposures for these various scenarios are assessed using data from MRID 43432901 (Maxey and Murphy, 1994) described above.

Dermal Exposure during Sorting / Culling / Packing

Following treatment with the pesticide, subsequent warehouse line stations have workers remove damaged fruit, sort based on appearance and quality, and pack the fruit into boxes. The following excerpts from Versar Inc.'s primary review describe the processes in more detail:

> Pears: The pears were received from orchards in 4 x 4 x 4 feet wood storage bins. The bins were placed in cold storage to achieve a pear core temperature of 32-35°F. Bins containing the pears were removed by forklift from cold storage and placed on a conveyor which introduced the entire bin to the dip tanks. After treatment, pears were conveyed out of the dip tank solution and onto the pear conveyor system where the cleaning phase began. Cleaning consisted of a mechanism to remove leaves and debris followed by a wash with neutral soap solution and a rinse with water. At this point, there is a pre-sort station which is used when the general pear quality is poor in order to remove damaged fruit. This pre-sort station was not used at any of the three pear packaging

facilities. Following the cleaning phase, other fungicides were applied. At Facilities 1 and 3, wax was then applied to the fruit. Next, the fruit was dried. The drying phase consisted of fans and/or long dryer units that recirculated air at 130-140°F. After the drying phase, the pears were sorted by sorters into different grades, based on appearance and quality. After grading and sorting, each pear was individually weighed by an automated system and then conveyed to the proper pear collection tubs for packing. Packers used one hand to grab thin copperized paper and the other hand to grab pears to wrap each pear individually before placing them into a box which generally held 40 to 50 pounds of pears. Packers would rotate to different tubs to pack different sizes of pears through their shift. They typically packed 180 to 300 boxes a day.

Citrus: Citrus fruit was brought directly from the orchard in large open trucks and mechanically conveyed into the packaging facility. The first step included cleaning the fruit using high pressure water rinses to remove dirt, leaves and debris. This was followed by a chlorine spray solution treatment to kill surface bacteria. In some cases, a pre-sort station was present for workers to sort out damaged fruit before the treatment phase. The next phase was the treatment phase, which consisted of using either foam (Facility 4) or spray (Facility 5 and Facility 6) application directly onto the fruit followed by brushing. A water rinse was applied immediately after the treatment and included a second segment of cleaning brushes. After treatment, sorters separated out damaged fruit at a pre-sort station. At Facilities 5 and 6, this area was in a small tented area and at Facility 4; this area was a large open area. These pre-sort stations were closest to the treatment area and the surface of the fruit was generally wet from the rinse with water following the treatment. After the pre-sort station, a wax and other fungicides were applied to the fruit and the fruit were then conveyed into a large recirculating dryer system which was maintained at 120 to 140°F. The fruit were then moved to the main sorting and grading area where fruit was sorted into appropriate grades, weighed using an automated system, and conveyed to the proper packaging area. Packaging was performed by hand and though the use of packaging machines. Periodically the operators of the packaging machines came into contact with the fruit periodically when the fruit on the machine needed adjustment and when hand packing operations were needed.

Maxey and Murphy (1994) measured dermal and inhalation exposure for workers performing these activities. The monitoring reflects individuals wearing a short-sleeve shirt with thin cotton gloves or finger "cots" (mostly to protect the fruit) without chemical resistant gloves – all typical of this industry. In order to present exposure estimates for use in any risk mitigation strategy assumptions are made to account for protection offered by additional layers of clothing or chemical-resistant gloves. The study did not include lower body measurements; however, it is reasonable to assume exposure to the legs for these activities is low, at least in comparison to the upper body. Because the data review was in 2005, certain current conventions may not apply to this dataset, including corrections for all field fortification recoveries. In this study, measurements were only corrected if matching field fortification recoveries were below 90%. These corrections compared with current methods are expected to have only a marginal influence on the overall results.

Analysis of the data appears to show that task, type of fruit, and facility can influence the magnitude of both dermal and inhalation exposure. Because sorters handle the treated fruit before the packers, it makes intuitive sense that they would experience higher exposures. Additionally, presenting separate risks for the different tasks can potentially aid in risk mitigation strategies. Speculation for potential differences between crops and facilities is more difficult.

Figures 1 and 2 below show dermal and inhalation exposure, respectively, normalized to the % active ingredient in the treatment solution, by crop, facility, and task. It is apparent that within the same facility, sorters generally appear to experience higher exposures than packers, so this is a reasonable separation in the data. While pears overall appear to result in higher exposures, it is unclear whether it is the machinery within a facility or the type of fruit that is causing the observed differences. (No facility treated both types of fruit to facilitate this kind of analysis.)

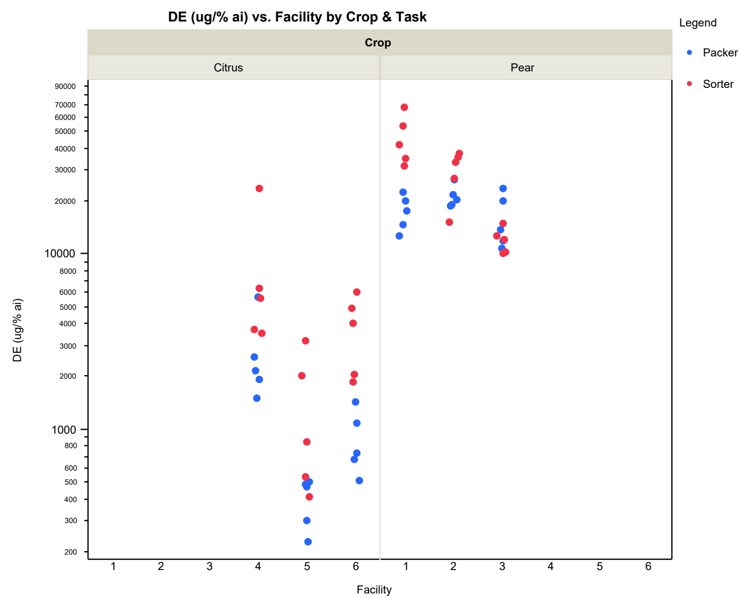

Figure 1: Dermal Exposure (ug/% ai) by Facility, Crop, and Activity

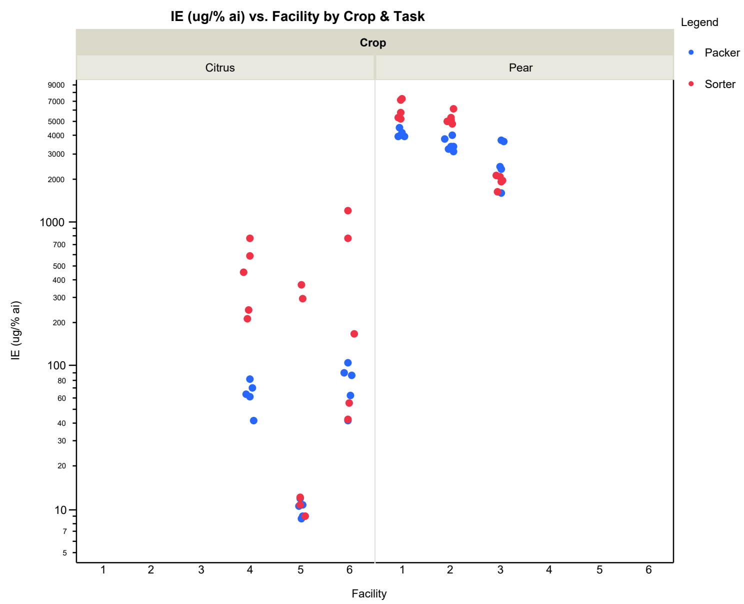

Figure 2: Inhalation Exposure (ug/% ai) by Facility, Crop, and Activity

Given the potential effects of these different variables, it is a reasonable approach to group sorters and packers for the purposes of exposure assessment. (Though presenting inhalation exposures separately for each task results in no meaningful difference, this is done to be consistent with the separation of dermal exposures by task). No additional sub-setting of the data by crop or facility will be conducted. A summary of these results is provided in Table 1 below:

<table>
<tr><th colspan="6">Table 1. Summary Analysis of Sorter/Packer Exposure Data from MRID 43432901</th></tr>
<tr><th colspan="2" rowspan="2">Statistic</th><th colspan="2">Dermal (µg/% ai)[6]</th><th colspan="2">Inhalation (µg/% ai)[7]</th></tr>
<tr><th>Sorters (n=30)</th><th>Packers (n=30)</th><th>Sorters (n=30)</th><th>Packers (n=31)</th></tr>
<tr><td colspan="2">Range</td><td>415 – 67900</td><td>229 – 26500</td><td>9.05 – 7310</td><td>8.71 – 4550</td></tr>
<tr><td colspan="2">GM[1]</td><td>8300</td><td>4020</td><td>823</td><td>374</td></tr>
<tr><td colspan="2">GSD[1]</td><td>3.99</td><td>5.13</td><td>7.76</td><td>11.1</td></tr>
<tr><td rowspan="2">AM[1]</td><td>Empirical[2]</td><td>16800</td><td>9760</td><td>2500</td><td>1810</td></tr>
<tr><td>Parametric[3]</td><td>21600</td><td>15300</td><td>6720</td><td>6760</td></tr>
<tr><td rowspan="2">95th Percentile</td><td>Empirical[4]</td><td>47800</td><td>22900</td><td>6690</td><td>4130</td></tr>
<tr><td>Parametric[5]</td><td>80700</td><td>59100</td><td>23900</td><td>19600</td></tr>
<tr><td colspan="6">[1] GM = geometric mean; GSD = geometric standard deviation; AM = arithmetic mean. Statistics are estimated assuming a lognormal distribution and independent measurements. Statistics can also be estimated using a variance component model accounting for correlation between measurements conducted within the same field study (i.e., measurements collected within the same facility).
[2] Simple average
[3] AM = GM*exp{0.5*((lnGSD)^2)}
[4] Based on the rank ordering
[5] 95th = GM * GSD^1.645
[6] Calculated as sum of inner dosimeter, outer arm dosimeter, and hand rinse measurements, normalized to % active ingredient in solution. Exposure monitoring is reflective of individuals wearing short-sleeve shirts without chemical-resistant gloves. The lower body was not measured. See Table 2 for estimates that consider additional clothing or PPE.
[7] Calculated as product of air concentration, breathing rate, and monitoring time (mg/m^3 * m^3/minute * minutes), normalized to % active ingredient in solution. Exposure monitoring reflects workers without respirators (NR = no respirator). See Table 2 for estimates that consider protection by respirators.</td></tr>
</table>

For exposure assessment, the recommended use of the data based on the analyses discussed above is presented in Table 2 below. As is standard practice for routine short-/intermediate-/ or long-term assessments, **the arithmetic mean is presented since it is the recommended default estimate.**

<table>
<tr><th colspan="4">Table 2. Post-Harvest Sorters/Packers: Recommended Unit Exposures (µg/% ai; arithmetic mean)[a]</th></tr>
<tr><th>Exposure Route</th><th>PPE[b]</th><th>Sorters</th><th>Packers</th></tr>
<tr><td rowspan="3">Dermal</td><td>Tshirt/NG</td><td>21600</td><td>15300</td></tr>
<tr><td>SL/NG</td><td>15500</td><td>10000</td></tr>
<tr><td>SL/G</td><td>10500</td><td>9500</td></tr>
<tr><td rowspan="3">Inhalation</td><td>NR</td><td>6720</td><td>6760</td></tr>
<tr><td>PF5</td><td>1340</td><td>1350</td></tr>
<tr><td>PF10</td><td>672</td><td>675</td></tr>
<tr><td colspan="4">[a] Means estimated as described in Table 1.
[b] SL = single layer (long pants, long sleeve-shirt, shoes/socks), calculated from exposure monitoring assuming 50% protection to forearms by a long-sleeve shirt; NG = no chemical-resistant gloves; G = chemical-resistant</td></tr>
</table>

gloves, calculated assuming a protection factor of 90%; NR = no respirator; PF5 = NR value * 0.2 (i.e., protection factor 5); PF10 = NR value * .10 (i.e., protection factor 10).

The assessment methodology using this data is as follows:

Dose (µg) = [UE (µg/% ai) * AR (% ai in solution) * AF] ÷ BW (kg)

Where:

UE = unit exposure (expressed as amount of exposure per % active ingredient in solution)

> Table 2 presents the recommended default estimates for dermal and inhalation unit exposures for various PPE levels.

AR = application rate

> The application rate is typically specified on the pesticide product label. To ensure proper units conversion, it should be expressed in terms of "% active ingredient in solution" which may require conversion for labels that express rates in terms of "mass active ingredient per volume solution".

AF = absorption factor (route-specific)

> If no information is available, 100% absorption of external exposure is typically assumed when an oral toxicity study is used to estimate dermal and inhalation risk. Route-specific toxicity dosing studies, on the other hand, account for absorption.

BW = body weight

> For adults (males and females combined) a default body weight of **80 kg** is recommended. A default body weight of **69 kg** is recommended for females (age 13 < 49), should it be required based on a chemical's toxicity.

Indirect Inhalation Exposure

Ambient/area air monitoring was also conducted in Maxey and Murphy (1994), documenting that the automated treatment process can indirectly lead to inhalation exposure to other workers not directly involved in the process. All samples were conducted in facilities that treated citrus fruit, so these results apply generically for all treatments. A summary is provided in Table 3 below.

Table 3. Summary Results for Ambient Air Samples

Statistic		**Inhalation Exposure (µg/% ai)[6] (n=22)**
Range		2.71 – 1570
GM[1]		96.7
GSD[1]		4.57
AM[1]	Empirical[2]	235

	Parametric[3]	307
95th Percentile	Empirical[4]	702
	Parametric[5]	1180

[1] GM = geometric mean; GSD = geometric standard deviation; AM = arithmetic mean. Statistics are estimated assuming a lognormal distribution and independent measurements. Statistics can also be estimated using a variance component model accounting for correlation between measurements conducted within the same field study (i.e., measurements collected within the same facility).
[2] Simple average
[3] AM = GM*exp{0.5*((lnGSD)^2)}
[4] Based on the rank ordering
[5] 95th = GM * GSD^1.645
[6] Calculated as product of air concentration, breathing rate, and monitoring time (mg/m^3 * m^3/minute * minutes), normalized to % active ingredient in solution. Exposure monitoring reflects workers without respirators (NR = no respirator). See Table 4 for estimates that consider protection by respirators.

In terms of exposure assessment categories, the recommended use of the data based on the analyses discussed above is presented in Table 4 below. As is standard practice for routine short-/intermediate-/ or long-term assessments, **the arithmetic mean is presented since it is the recommended default estimate.** Additionally, since the results do not allow differentiation by crop or any other treatment characteristic, these estimates should be generically applied to all post-harvest commodity treatments.

Table 4. Post-Harvest Ambient Air: Recommended Inhalation Unit Exposures (µg/% ai; arithmetic mean)[a]

NR	307
PF5	61.4
PF10	30.7

[a] Means estimated as described in Table 3.
[b] NR = no respirator; PF5 = NR value * 0.2 (i.e., protection factor 5); PF10 = NR value * .10 (i.e., protection factor 10).

Similar to sorters and packers, the methodology using the ambient exposure data to assess indirect inhalation exposure is as follows:

$$\text{Dose } (\mu g) = [\text{UE } (\mu g/\% \text{ ai}) * \text{AR } (\% \text{ ai in solution}) * \text{AF}] \div \text{BW (kg)}$$

Where:

UE = unit exposure (expressed as amount of exposure per % active ingredient in solution)

> Table 4 presents the recommended default estimates for inhalation unit exposures for various PPE levels.

AR = application rate

> The application rate is typically specified on the pesticide product label. To ensure proper units conversion, it should be expressed in terms of "% active ingredient in solution" which may require conversion for labels that express rates in terms of "mass active ingredient per volume solution".

AF = absorption factor (route-specific)

If no information is available, 100% absorption of external exposure is typically assumed when an oral toxicity study is used to estimate dermal and inhalation risk. Route-specific toxicity dosing studies, on the other hand, account for absorption.

BW = body weight

For adults (males and females combined) a default body weight of **80 kg** is recommended. A default body weight of **69 kg** is recommended for females (age 13 < 49), should it be required based on a chemical's toxicity.